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SOME STRENGTH TESTS OF STIFFENED CURVED SHEETS LOADED IN SHEAR

By Patrick T. Chiarito

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

WASHINGTON

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RESTRICTED BULLETIN

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By Patrick T. Chiarito

SUMMARY

Results are presented of strength tests of a number of curved-sheet specimens of 24S-T aluminum alloy stiffened longitudinally and transversely and loaded in shear. The specimens were of two related types: curved-web beams and cylindrical shells.

INTRODUCTION

The problem of predicting the strength of stiffened curved sheet under shear loads has received only a moderate amount of attention in the past. One particular aspect of the theory has been treated to some extent, namely, the theory of pure diagonal tension in curved sheet. It is well known, however, that the theory of pure diagonal tension is generally too conservative for use in design. The investigations by Schapitz (reference 1) and by Limpert (reference 2) were not very conclusive, and the investigation by Thorn (reference 3) was intended only to demonstrate the strength of a particular type of construction. An investigation of stiffened curved sheet under shear loads has therefore been started by the National Advisory Committee for Aeronautics.

The project is of considerable magnitude and will not be completed for some time. For these reasons and because of the lack of available information, it was considered desirable to publish, before completion of the project, such test results as might be of some direct usefulness to the designer. The present paper describes the specimens tested to date and gives the observed skin-buckling stresses and the ultimate strengths developed.

SYMBOLS

t	thickness of skin or web, inches
d	longitudinal distance between adjacent rings, inches
h	circumferential distance between stringers, inches
h_e	distance between centroids of beam flanges, inches
A_R	cross-sectional area of ring, square inches
A_S	cross-sectional area of stringer, square inches
R	radius of curvature of sheet, inches
P	load applied at tip of beam, kips
T	torque applied at tip of cylinder, kip-inches
τ	shear stress in sheet, ksi

Subscripts:

cr	critical
ult	ultimate

TEST SPECIMENS

The specimens used were of two related types: curved-web beams and cylindrical shells (fig. 1). They were of 24S-T aluminum-alloy sheet, stiffened longitudinally by extruded 24S-T alloy angles 30° apart and stiffened transversely by rings formed from 24S-T alloy sheet. The pertinent dimensions of the specimens are given in table 1. The flanges of the curved-web beams were structural-steel angles; double angles were used for the heavier beams. The shell specimens had three longitudinal skin splices located under stringers 120° apart.

The stringers were placed on the outside of the sheet because floating rings were considered undesirable for the beam tests and because the tests of reference 3 indicated that tests of specimens with notched rings or with intercostal stiffeners would not yield results which could be generalized.

As indicated in figure 1, the beams as well as the shells were equipped with special root fittings that were used to attach the test specimens to a heavy steel structure. The tip fitting of the beams was essentially a steel plate that permitted the test load to be applied at the estimated shear center of the cross section. Both beam flanges were supported against possible lateral deflections at intervals of approximately 15 inches along the span. The tip fitting of the shells was a heavy steel ring of angle section. Torque was applied to this ring as a couple by means of a double bell crank.

TEST RESULTS

The test results are summarized in table 2. The load at which the sheet began to show shear buckles was determined by observing the reflection in the sheet of a straight edge while it was being rolled over the curved surface of the sheet in a direction perpendicular to the expected folds. Comparisons of the buckling stresses for the individual panels of one beam or cylinder showed wide variations. In some beams the first buckles occurred on the tension side of the beam, whereas theoretically the first buckles should occur on the compression side.

The shear stress developed by the sheet was calculated for the beams by the expression

$$\tau_{ult} = \frac{P_{ult}}{h_e t}$$

and for the cylinders by the relationship

$$\tau_{ult} = \frac{T_{ult}}{2\pi R^2 t}$$

As noted in table 2, the failures were divided into failures involving rupture of the sheet and failures not involving such rupture. This division is natural because the strength of the sheet determines the upper limit of the strength of the entire structure. Figures 2 and 3 show the stiffened curved sheets after failure.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va.

REFERENCES

1. Schapitz, E.: The Twisting of Thin-Walled, Stiffened Circular Cylinders. NACA TM No. 878, 1938.

2. Limpert, G.: The Buckling of Curved Tension-Field Girders. NACA TM No. 846, 1938.

3. Thorn, K.: Spannungsmessungen an gekrümmten Schubwänden eines Schalenrumpfes. Jahrb. 1937 der deutschen Luftfahrtforschung, R. Oldenbourg (Munich), pp. I 459-I 463.

TABLE 1.- DIMENSIONS OF TEST SPECIMENS

Specimen	t (in.)	d (in.)	h (in.)	Rings			Stringers			h_e (in.)
				Section	Nominal size (in.) (a)	Area, A_R (sq in.)	Section	Nominal size (in.)	Area, A_S (sq in.)	
Curved-web beams										
1	0.0154	15.0	7.85	Z	$\frac{9}{16}\times\frac{9}{16}\times0.040$	0.0650	L	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	0.1306	28.0
2	.0145	7.5	7.85	L	$\frac{9}{16}\times\frac{9}{16}\times0.040$	.0389	L	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	.1340	28.0
3	.0143	7.5	7.85	Z	$\frac{9}{16}\times\frac{9}{16}\times0.040$	.0566	L	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	.1345	28.0
4	.0385	7.5	7.85	Z	$\frac{11}{16}\times\frac{3}{4}\times0.080$	.1275	L	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	.1350	28.0
5	.0394	7.5	7.85	Z	$\frac{11}{16}\times\frac{3}{4}\times0.080$	.1248	L	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	.1370	28.5
6	.0154	15.0	7.85	Z	$\frac{11}{16}\times\frac{3}{4}\times0.064$	.1093	L	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	.1360	28.0
7	.0395	7.5	7.85	Z	$\frac{11}{16}\times\frac{3}{4}\times0.080$	.1225	L	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	.1352	28.5
8	.0150	15.0	7.85	Z	$\frac{11}{16}\times\frac{3}{4}\times0.051$	.0960	L	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	.1360	28.0
9	Special beam		------	-------	-------------	---------	--------	------------	--------	------
10	.0154	15.0	7.85	Z	$\frac{11}{16}\times\frac{3}{4}\times0.040$	.0756	L	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	.1385	28.0
Cylindrical shells										
1	0.0150	15.0	7.85	Z	$\frac{9}{16}\times\frac{9}{16}\times0.040$	0.0685	L	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	0.1332	
2	.0157	7.5	7.85	L	$\frac{9}{16}\times\frac{9}{16}\times0.040$	.0385	L	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	.1335	

[a]For Z's, first dimension is the width of the flanges.

TABLE 2.- TEST RESULTS

Curved-web beams						
Specimen	Observed τ_{cr} (ksi)			P_{ult} (kips)	τ_{ult} (ksi)	Type of failure (d)
	(a)	(b)	(c)			
1	1.40	5.22	1.63	8.16	18.95	A
2	1.82	3.45	2.00	8.31	20.45	B
3	1.50	3.75	2.50	10.00	25.00	A
4	5.57	11.60	5.57	(e)	(e)	Flange
5	6.25	10.30	6.25	(e)	(e)	Rivets
6	.93	2.32	2.09	9.80	22.75	A
7	7.10	14.20	7.10	28.05	24.90	B
8	1.43	2.14	2.02	9.30	22.20	A
9	Special beam		------	----------	-------	---------
10	1.76	2.29	2.23	7.60	17.65	B

Cylindrical shells					
Specimen	Observed τ_{cr} (ksi)		T_{ult} (kip-in.)	τ_{ult} (ksi)	Type of failure (d)
	(a)	(f)			
1	0.49	2.82	324.00	15.25	A
2	1.68	3.38	417.00	18.70	A

[a]Shear stress at which buckles first appeared in any panel.

[b]Shear stress at which all panels at middle stringer buckled.

[c]Shear stress at which buckles first appeared at middle stringer.

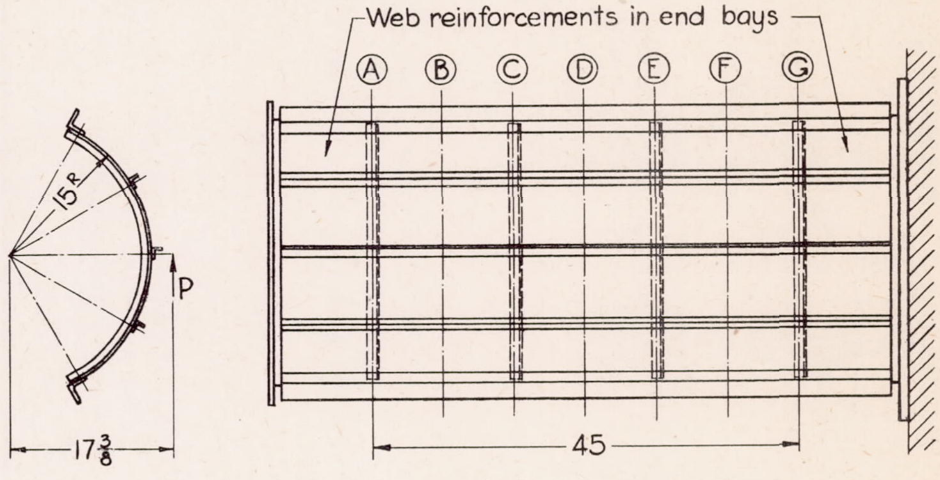
[d]Type of failure:

A - Web torn, rings and stringers buckled.

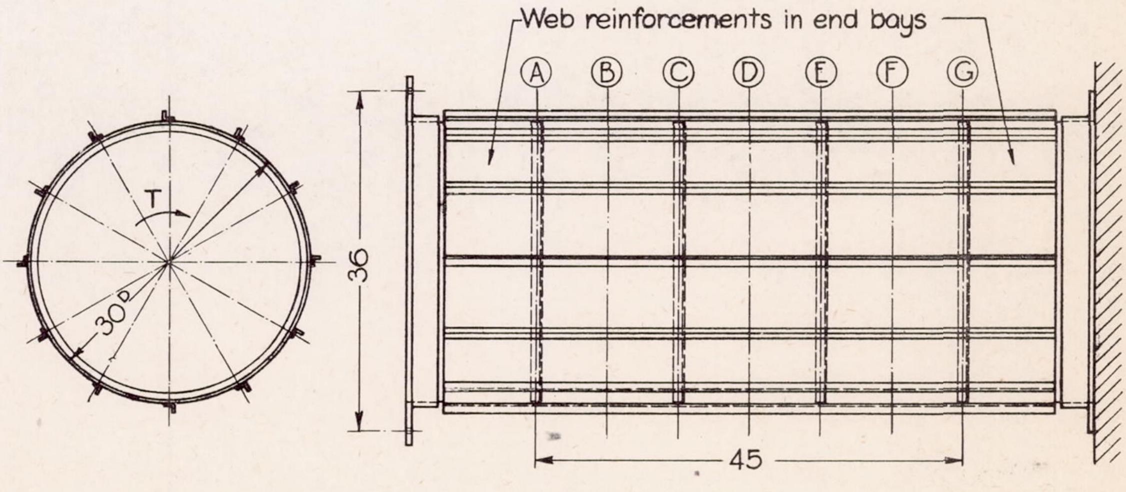
B - Web not torn, rings and stringers buckled.

[e]Premature failure.

[f]Shear stress at which all panels in complete bay buckled.

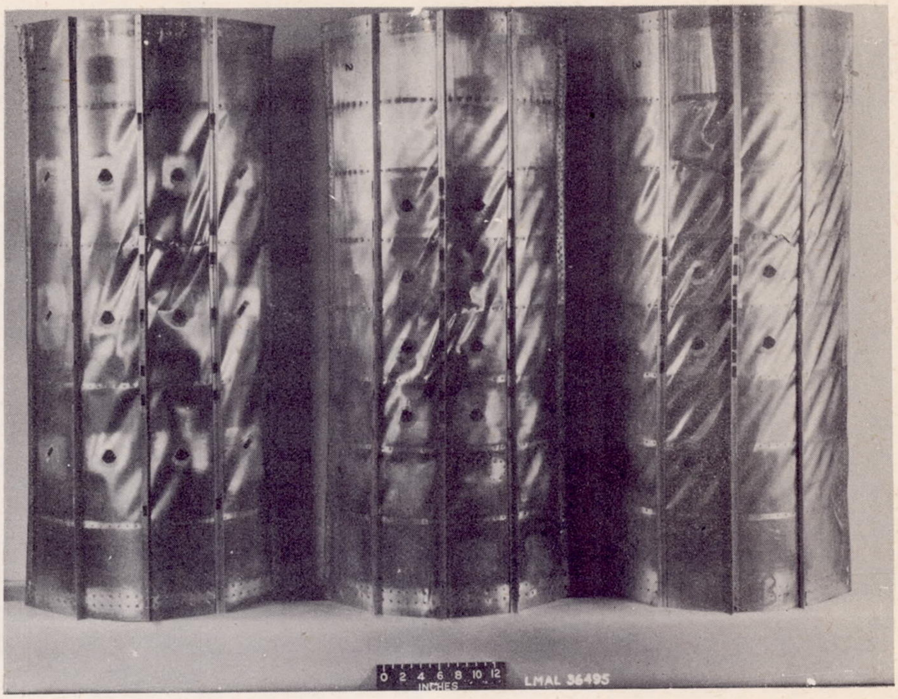


(a) Curved-web beam.



(b) Cylindrical shell.

Figure 1.-Typical test specimens.



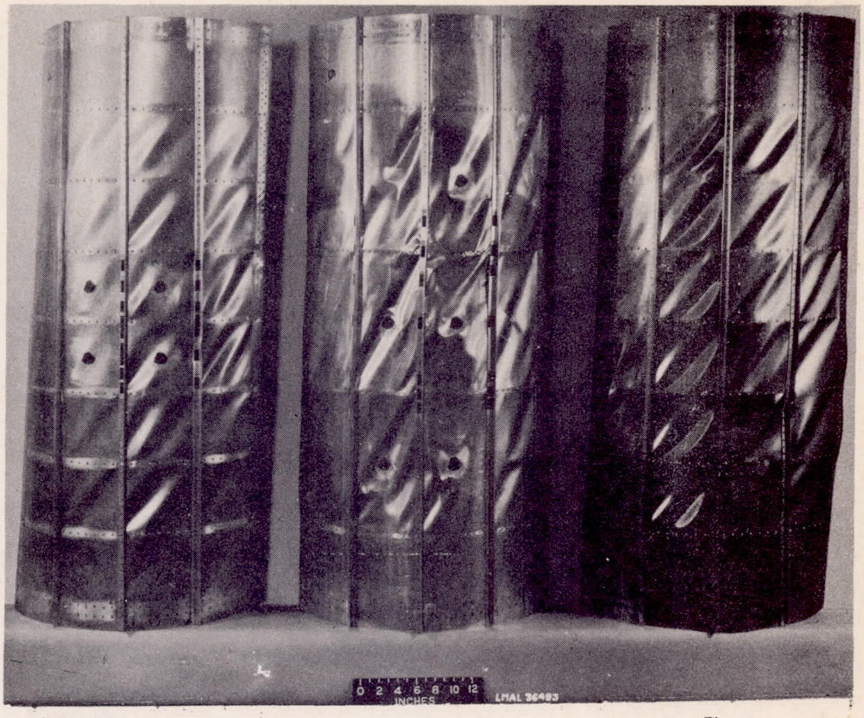
BEAM 1 2 3

(a) Outside of beams 1, 2, and 3.

BEAM 1 2 3

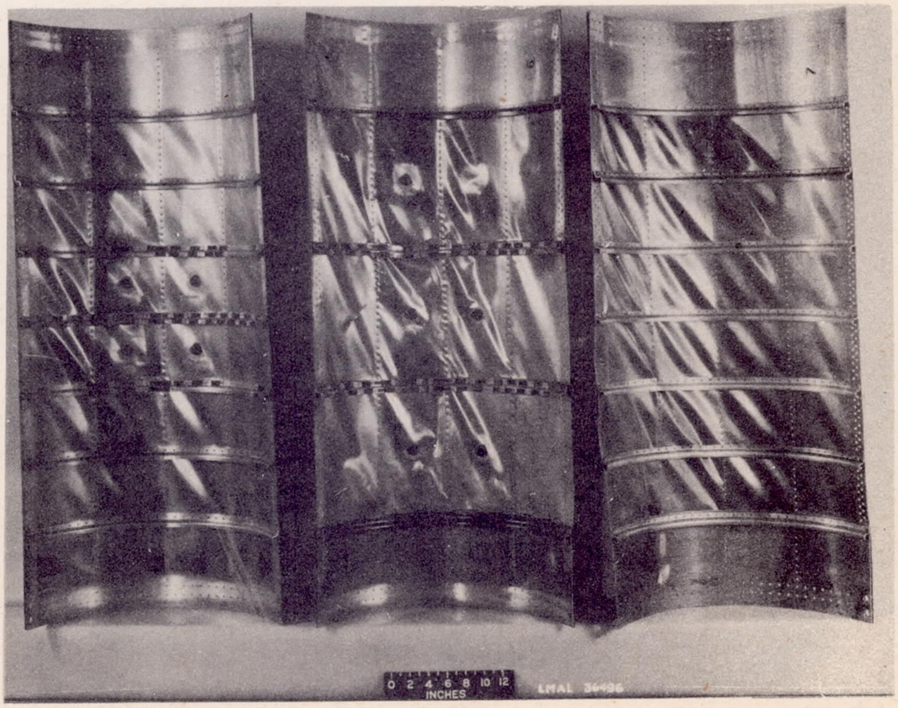
(b) Inside of beams 1, 2, and 3.

Figure 2.- Curved-web beams after failure.



BEAM 4 6 7

(c) Outside of beams 4, 6, and 7.



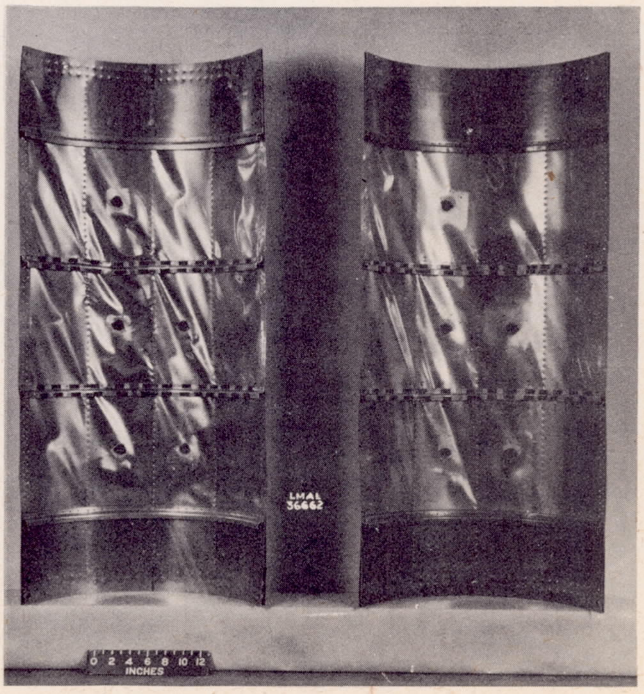
BEAM 4 6 7

(d) Inside of beams 4, 6, and 7.

Figure 2.- Continued.

BEAM 8 10

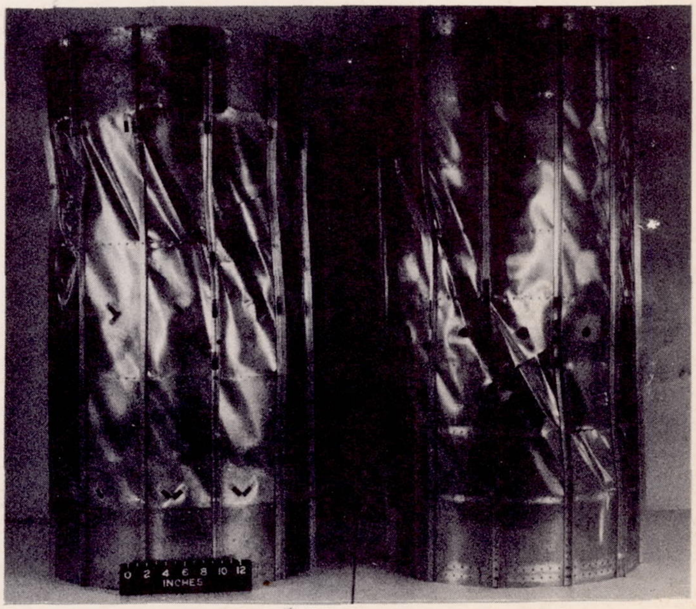
(e) Outside of beams 8 and 10.



BEAM 8 10

(f) Inside of beams 8 and 10.

Figure 2.- Concluded.



SHELL 1 2

Figure 3.- Cylindrical shells 1 and 2 after failure.